Journal Applied Science and Technology on Naval Engineering

Vol. 4, No. 1, February 2026: page 12-18
ISSN: 3031-8866
DOI: 10.54378/astne.v4i2.13487

ANALYSIS OF MECHANICAL STRENGTH OF KEVLAR, CARBON, AND GLASS FIBER POSITIONS REINFORCED WITH EPOXY RESIN FOR FIBERGLASS SHIP HULL ZONES

Khanissa Alfita Santoso Putri[a], Amir Marasabessy[a,*]

[a] *Teknik Perkapalan, Universitas Pembangunan Nasional "Veteran" Jakarta, Indonesia*

Abstract

The use of fiber-reinforced polymer (FRP) composite materials has become a primary solution in modern ship hull construction to reduce structural weight without compromising strength. This study aims to analyze the mechanical strength characteristics of hybrid composite materials reinforced with Kevlar, carbon, and glass fibers using an epoxy resin matrix, with particular emphasis on various stacking sequence configurations. The main focus of the research is to evaluate the effect of fiber stacking order on tensile strength, yield strength, and elastic modulus. Mechanical performance was assessed through tensile testing conducted in accordance with ISO 527-4, a standard specifically intended for determining the tensile properties of unidirectional fiber-reinforced composites. Test specimens were fabricated using the hand lay-up method, with fibers uniformly oriented at a 0° direction. The results indicate that the stacking sequence configuration has a significant influence on mechanical performance. The placement of carbon fiber, which possesses a very high elastic modulus (up to 400 GPa), contributes substantially to the overall stiffness of the composite. Meanwhile, Kevlar fiber, with its high failure strain (approximately 14%), enhances the material's energy absorption capability. This analysis provides technical recommendations for optimal fiber layer configurations, particularly for ship hull zones that require high structural strength and durability under marine environmental conditions.

Keywords: *Hybrid Composites, Kevlar, Carbon, Glass Fiber, Ship Hull*

1. Introduction

Fiber Reinforced Polymer (FRP) composites have become a primary material choice in modern ship hull construction due to their high strength-to-weight ratio, corrosion resistance, and excellent durability in marine environments. Since their introduction in the maritime sector after World War II, FRP materials have increasingly replaced traditional steel and wood structures, particulary in small-to medium-sized vessels, to improve fuel efficiency and reduce maintenance costs (Rubino et al., 2020) The continuous development of marine comp composites has encouraged the exploration of various fiber and resin matrix combinations to meet the specific mechanical and environmental requirements of fiberglass ship hulls.

Epoxy resin is widely used as the matrix in marine FRP composites because of its strong adhesion to reinforcing fibers, high chemical resistance to sweater, and effective stress distribution between laminate layers, which reduces stress concentration and the risk of delamination (Calabrese et al., 2019). The mechanical performance of FRP laminates is strongly influenced by the fiber stacking sequence, especially in hybrid composites combining glass, carbon, and kevlar fibers. Several studies have examined the use of epoxy-based hybrid composites with a combination of kevlar, carbon, and glass fibers. (Stephen et al., 2021) stated that the fiber stacking sequence plays a critical role in determining the mechanical response and damage mechanisms of the composite. The results this study are expected to provide recommendations for the best sequence of material fiber positions for use in fiberglass boat hull structures, which require high strength and resistance to sea conditions.

2. Literature Review

2.1 Composite materials

Composite materials are engineered materials composed of a reinforcement and a matrix that are combined to produce superior mechanical properties compared to their individual constituents. In marine applications, Fiber

* 2110313010@mahasiswa.upnvj.ac.id:

Reinforced Polymer (FRP) composites reinforced with glass, carbon, or aramid fibers are widely used in ship structures due to their high strength-to-weight ratio, corrosion resistance, and durability in harsh marine environments. The application of FRP in ship hull structures aims to reduce structural weight without compromising strength, thereby improving fuel efficiency and operational performance (Rubino et al., 2020). In addition, the hull zone is the most critical part of a vessel, as it must withstand impact loads and aggressive seawater exposure, making composite materials a suitable choice for small to medium-sized marine vessels (Setyawan & Marasabessy, 2022).

2.2 Reinforcing Fibers

Reinforcing fibers are the primary load-bearing components in composite materials, responsible for providing tensile strength and stiffness to the structure. In marine composite applications, commonly used fibers include Kevlar (aramid), carbon, and glass fibers, each offering distinct mechanical advantages depending on the structural requirements. Kevlar fibers are characterized by high tensile strength and excellent impact resistance, making them suitable for energy-absorbing applications, while carbon fibers provide very high stiffness and low weight, contributing to improved structural efficiency. Glass fibers, particularly E-glass, remain the most widely used reinforcement in marine composites due to their good mechanical properties, resistance to moisture and chemical degradation, and cost-effectiveness. Consequently, the selection and configuration of reinforcing fibers play a critical role in optimizing the mechanical performance of composite ship hull structures (Rubino et al., 2020); (Calabrese et al., 2019).

2.3 Resin epoxy

Epoxy resin–based composites are widely used as advanced composite materials due to their excellent mechanical properties, thermal stability, and chemical resistance. As a thermosetting polymer, epoxy resin serves as the matrix that binds reinforcing fibers such as glass, carbon, or Kevlar fibers and effectively transfers loads throughout the composite structure. Epoxy resins offer strong adhesion, low shrinkage, good electrical insulation, and suitable viscosity for effective fiber impregnation, making them particularly suitable for marine applications such as ship hull structures. Despite these advantages, epoxy resins exhibit inherent brittleness and relatively low fracture toughness, which can be improved through the incorporation of micro- or nano-scale fillers to enhance overall composite performance (Bello et al., 2015).

2.4 Mechanical Strength Testing

Mechanical strength testing was performed using the tensile test method in accordance with ISO 527-4, which is specifically designed to evaluate the tensile properties of polymer matrix composites reinforced with continuous fibers. This standard ensures consistency in specimen geometry, testing procedure, and loading conditions, allowing reliable comparison of tensile strength, yield strength, and modulus of elasticity. Tensile strength is determined from the maximum applied load divided by the specimen cross-sectional area, while the modulus of elasticity is calculated from the stress–strain relationship. Specimen dimensions and configurations followed ISO 527-4:2023(E)**,** and the test results were evaluated based on the minimum mechanical requirements for E-glass fiberglass composites specified by the Indonesian Classification Society (BKI) for ship hull structures.

The strength standards are regulated based on the BKI Rules (Rules for Non-Metallic Materials, Part 1, 2014 Edition):

a. Tensile strength can be determined using the following formula:

$$\sigma u = \frac{pmax}{\mathrm{A}} \qquad \textit{2.1}$$

Where :
$pmax$ = maximum load required to cause fracture of the plate specimen (N)
A = cross-sectional area of the specimen (mm^2)

b. Modulus of elasticity can be determined using the following formula:

$$E = \frac{\mathrm{\sigma u}}{\mathrm{e}} \qquad \textit{2.2}$$

Where :
σu = tensile stress (N/mm²)
e = strain, defined as the ratio of the increase in specimen length after tensile testing to the initial specimen length

$$e = \frac{L\Delta}{Lo} \qquad 2.3$$

For fiberglass specimens using mat and roving fiber reinforcement with a plate thickness of 6-8 mm, the minimum tensile strength value for the test is:

$$Rz = 1078\Phi^2 - 510\Phi + 102 = 43{,}12 \quad N/mm^2 \qquad 2.4$$

Where: Φ = *percentage of fibre volume content*: $0{,}2 \leq \Phi \leq 0{,}6$, $\Phi = 0{,}2$

2.5 Variation of Fiber Layer Stacking Sequence

In laminated composites, the fiber stacking sequence refers to the arrangement of reinforcing fibers within a laminate structure and plays a critical role in determining load distribution and mechanical properties such as tensile strength, flexural strength, stiffness, and impact resistance. The final performance of composite laminates is highly dependent on fiber orientation, number of layers, and the sequence and type of fibers used, as emphasized by (Hancox, 1996). In hybrid composites, which combine two or more types of fibers such as carbon, Kevlar, and glass within a single matrix, the stacking sequence is designed to exploit the advantages of each fiber type. High-strength fibers like carbon placed in the outer layers enhance stiffness, while tougher fibers such as Kevlar in inner layers improve impact resistance and reduce the risk of delamination. Consequently, fiber stacking sequence also influences interlaminar shear strength, making it a key design parameter for marine applications such as fiberglass ship hulls.

3. Research Method

The research methodology used to evaluate the mechanical performance of hybrid composite laminates reinforced with Kevlar, carbon, and glass fibers using an epoxy resin matrix for fiberglass ship hull applications. The study begins with a literature review to establish the theoretical background on composite materials, fiber characteristics, and tensile testing standards. The research variables are defined, where the independent variables are fiber type and stacking sequence, the dependent variable is tensile strength, and the controlled variables include resin type, specimen dimensions, fiber orientation (0°), and fabrication method.

The composite specimens were fabricated using the hand lay-up method due to its simplicity and common use in small- to medium-scale fiberglass ship construction. Materials used include epoxy resin and hardener, woven roving glass fiber, chopped strand mat (CSM), carbon fiber, and Kevlar fiber. The fibers were arranged in predetermined stacking sequences to investigate the effect of fiber position on mechanical properties. Fabrication was carried out by sequentially layering fibers and resin on a melamine mold, followed by curing at room temperature. After curing, the composite panels were cut and finished into tensile test specimens according to ISO 527-4 dimensional requirements.

Mechanical testing was conducted using a computerized universal tensile testing machine to obtain tensile strength, yield strength, and elastic modulus values. Each variation was tested using multiple specimens to ensure data reliability and repeatability. The collected data were analyzed quantitatively by calculating average values and comparing the mechanical performance of each stacking sequence. This methodology enables a systematic evaluation of how fiber positioning influences the tensile behavior of hybrid composites, providing a technical basis for selecting optimal laminate configurations for fiberglass ship hull zones.

4. Results and Discussion

4.1 Specimen Manufacturing Process

The manufacturing process of composite specimens reinforced with Kevlar, carbon, and glass fibers using an epoxy resin matrix was carried out at the ship production workshop of the Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta. The process began with the preparation of a melamine mold coated with mirror glaze to facilitate specimen removal and to obtain a smooth surface finish. The laminate was then fabricated using the hand lay-up method by sequentially applying chopped strand mat (CSM) 300 gsm and 450 gsm, woven roving 600 gsm, Kevlar fiber 200 gsm, and carbon fiber 200 gsm according to the planned stacking sequence variations.

Each layer was impregnated with epoxy resin using a resin-to-hardener ratio of 2:1 to ensure optimal fiber wetting and to minimize air voids. The CSM layers served as the base and outer layers to improve surface quality and laminate stability, while the main reinforcing fiber layers contributed to the mechanical strength of the composite. Variations in fiber stacking sequence were applied to evaluate their effect on the tensile performance of the specimens.

4.2 Tensile Test Specimen Cutting Process

After the laminates were fully cured, the composite plates were measured and marked according to the standard dimensions for tensile test specimens. This marking process was conducted to ensure uniformity and consistency among specimens. Initial cutting was performed using a handheld grinder along the marked lines, with careful handling to prevent fiber damage.

Subsequently, the specimens were finished using a belt sander to smooth the edges and to achieve precise dimensions in accordance with the testing standard. This finishing process ensured that the specimens met the required geometric tolerances, thereby improving the accuracy and reliability of the tensile test results.

4.3 Implementation of Specimen Testing

Figure 1

Table 1

No	Pengujian Mekanis	Bahan/material	Panjang (mm)	Lebar (mm)	Tebal (mm)
1.	Uji Tarik	*Fiberglass*	245	25	6,5

The tensile testing of the specimens was conducted using a universal tensile testing machine in accordance with the ISO 527-4 standard to ensure consistency and reliability of the results. Each specimen was carefully mounted on the testing grips and subjected to a gradually increasing tensile load until failure, while the machine automatically recorded load and elongation data to generate stress–strain curves for each stacking sequence variation. All tests were performed under identical conditions to maintain data validity and comparability.

The results indicate that fiber stacking sequence significantly influences the mechanical behavior of the hybrid composites. Laminates with a higher proportion of carbon fiber exhibited greater stiffness, whereas configurations containing Kevlar fibers showed higher elongation before failure, indicating improved energy absorption capability. These findings confirm that stacking sequence plays a crucial role in determining tensile strength, yield strength, and elastic modulus, highlighting the importance of selecting an appropriate fiber arrangement for optimal performance in fiberglass ship hull applications.

4.4 Analysis of Test Results

Figure 2

Table 2

Kode Sampel *Sample Code*	**Ukuran** *Dimension (mm)*		**Berat** *Weight (gr)*	**Luas Penampang** *Cross Section Area (mm²⁾)*	**Beban Maksimum** *Maximum Load (Newton)*	**Kuat Tarik** *Tensile Streng*	
	Width	*Thickness*				**kN**	**MPa**
Rata rata V1	245	6.5	42,33	180	8.552	8,5	53,66
Rata rata V2	245	6.5	42,66	180	11.633	11,6	73,33
Rata- Rata V3	245	6.5	41,66	180	13.163	13,1	82,33

The three composite laminate variations with a 0° fiber orientation exhibit significant differences in tensile strength due to variations in layer arrangement. Variation 1 shows the lowest tensile strength of 53.66 MPa, attributed to the dominance of fiberglass and the placement of only one carbon fiber layer in the middle of the laminate, which limits load-bearing effectiveness because the outer layers have lower elastic modulus. In Variation 2, the tensile strength increases to 73.33 MPa as a result of placing two Kevlar layers closer to the outer surfaces, creating a more balanced laminate structure that improves load transfer along the fiber direction. Variation 3 demonstrates the best performance, achieving the highest tensile strength of 82.33 MPa, due to the strategic placement of two carbon fiber layers on the top and bottom surfaces, which are the most effective positions for resisting maximum tensile strain during testing.

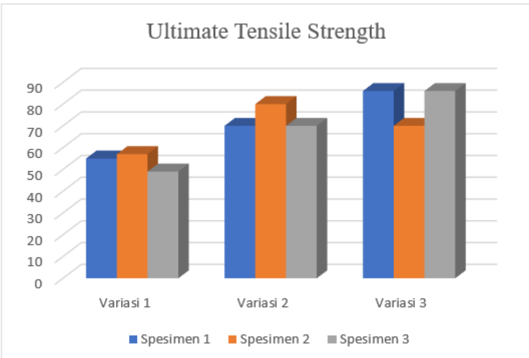

Figure 3

Table 3

Kode Sampel *Sample Code*	**Ukuran** *Dimension (mm)*		**Berat** *Weight (gr)*	**Luas Penampang** *Cross Section Area (mm²⁾)*	**Titik Luluh** *Yield Point* (Newton)	**Kuat Luluh** *Yield Streng*	
	Width	*Thickness*				**kN**	**MPa**
Rata rata V1	245	6.5	42,33	180	5210	5,21	33
Rata rata V2	245	6.5	42,66	180	5574	5,57	35

Rata- Rata V3	245	6.5	41,66	180	3401	3,40	21

The yield strength values show clear differences among the three composite laminate variations with a 0° fiber orientation, despite having identical dimensions and cross-sectional areas. Variation 1 exhibits an average yield load of 5.21 kN, corresponding to a yield strength of 33 MPa, indicating moderate elastic load-bearing capability that is limited by the dominance of fiberglass layers and less optimal placement of high-strength materials. Variation 2 demonstrates the highest yield strength of 35 MPa with an average yield load of 5.57 kN, reflecting a more effective load distribution in the elastic region due to a more balanced combination of fiberglass and Kevlar layers. In contrast, Variation 3 shows the lowest yield strength of 21 MPa with an average yield load of 3.40 kN, indicating that although it achieves high ultimate tensile strength, the laminate enters the plastic deformation region earlier due to its higher stiffness, confirming that laminate configuration strongly influences the elastic load-bearing behavior of the composite.

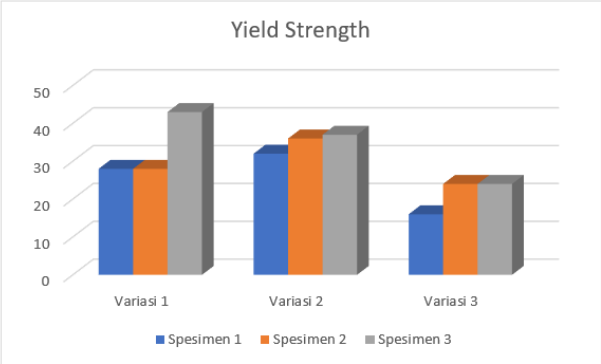

Figure 4

Table 4

Kode Sampel *Sample Code*	**Yeild Strength *(Mpa)***	**ΔL *(mm)***	**Strain (ε = ΔL /Lo)**	**Modulus elastilitas (Mpa) = σ / ε**
	MPA			
V1-S1	28	1,2	0,049	571,667
V1-S2	28	1,3	0,053	527,692
V1-S3	43	1,2	0,049	877,917
Rata rata (V1)	33	1,23	0,050	657,317
V2-S1	32	1,4	0,057	560,000
V2-S2	36	1,1	0,045	801,818
V2-S3	37	1,3	0,053	697,308
Rata rata (V2)	35	1,26	0,051	680,556
V3-S1	16	1,1	0,045	356,364
V3-S2	24	1,2	0,049	490,000
V3-S3	24	1,4	0,057	420,000
Rata rata (V3)	21	1,23	0,050	418,293

The elastic modulus results indicate significant differences in material stiffness among variations V1, V2, and V3. Variation V2 exhibits the highest average elastic modulus (680.556), compared to V1 (657.317) and V3 (418.293), indicating that V2 provides the greatest stiffness and mechanical stability. This superior performance is attributed to a more effective distribution of carbon, Kevlar, and glass fibers within the epoxy matrix, allowing more efficient stress transfer between the fibers and the matrix. In contrast, V3 shows the lowest elastic modulus, suggesting a higher tendency for elastic deformation under applied loads and making it less suitable for applications requiring high stiffness. Overall, these results confirm that fiber positioning significantly influences stiffness, with V2 being the most suitable configuration for fiberglass ship hull structures that demand high elastic resistance and structural rigidity.

5. Conclusion

Based on the research results, it can be concluded that variations in fiber stacking sequence in fiberglass composites have a significant effect on the tensile strength and elastic modulus of hybrid composites. The placement of carbon fiber in the outer layers produces the highest tensile strength, while laminates dominated by fiberglass with carbon fiber positioned in the middle exhibit the lowest tensile strength. Hybrid laminate configurations combining carbon, Kevlar, and glass fibers provide optimal mechanical performance, where carbon fibers enhance strength and stiffness, Kevlar fibers improve toughness and impact energy absorption, and glass fibers contribute to structural balance and cost efficiency. All tested laminate variations meet the tensile strength requirements specified by the BKI Rules (Rules for Non-Metallic Materials Part 1, 2014 Edition), with tensile strength values exceeding the minimum limit of 43.12 MPa and remaining below the maximum limit of 100 MPa, confirming that the developed composites are suitable as strong, lightweight, and safe alternative materials for fiberglass ship hull applications.

For future research and further improvement, several recommendations are proposed. Additional tests such as water absorption and seawater corrosion resistance are suggested to evaluate the long-term durability of the composites in marine environments. Future studies may also investigate different fiber orientation angles (e.g., ±45°) in addition to stacking sequence variations to assess their influence on shear strength. The use of the vacuum infusion method is strongly recommended to achieve a more precise fiber–resin ratio and minimize void formation that may reduce mechanical performance. Furthermore, a comparison between experimental results and numerical simulations based on Finite Element Analysis (FEA) is suggested to provide a more detailed validation of stress distribution in ship hull structures.

Reference

Rubino, F., Nisticò, A., Tucci, F., & Carlone, P. (2020). Marine Application of Fiber Reinforced Composites: A Review. Journal of Marine Science and Engineering, 8(1), 26. https://doi.org/10.3390/jmse8010026

Calabrese, L., Fiore, V., Scalici, T., & Valenza, A. (2019). Experimental assessment of the improved properties during aging of flax/glass hybrid composite laminates for marine applications. Journal of Applied Polymer Science, 136(14). https://doi.org/10.1002/app.47203

Stephen, C., Shivamurthy, B., Mourad, A.-H. I., & Selvam, R. (2021). *High-velocity impact behavior of hybrid fiber-reinforced epoxy composites*. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 43, 431. https://doi.org/10.1007/s40430-021-03139-6

Bello, S. A., Agunsoye, J. O., Hassan, S. B., Kana, M. G. Z., & Raheem, I. A. (2015). Epoxy resin based composites, mechanical and tribological properties: A review. *Tribology in Industry*, *37*(4), 500–524.

Hancox, N. L. (1996). Engineering mechanics of composite materials. *Materials & Design*, *17*(2), 114. https://doi.org/10.1016/s0261-3069(97)87195-6

Setyawan, B. A., & Marasabessy, A. (2022). Perancangan Awal Lambung Kapal Kepresidenan Dari Komposit Woven Kevlar-Rami-Polyester. *Jurnal Teknologi*, *14*(2), 174–182. https://dx.doi.org/10.24853/jurtek.14.2.173-182